Reactive Distillation based Algal Biodiesel Production: Optimization, Process Intensification and By-Product Utilization

Biswarup Mondal (14CH91R14)

Abstract

Algal biodiesel is widely accepted as a sustainable and alternative transportation fuel. In view of this, at first, a reactive distillation (RD) based process has been developed and techno-economic assessment is made to show its superiority over conventional multiunit (reactor followed by distillation) system. The compatibility of the RD column is extended for various catalysts, including homogeneous acid, heterogeneous base, nano-catalyst and mixed metal oxide. The optimal process configuration is identified using the elitist non-dominated sorting genetic algorithm (NSGA-II) embedded with technique for order of preference by similarity to ideal solution (TOPSIS). This optimization problem is formulated with multiple conflicting objectives to maximize biodiesel purity, and minimize total annual cost and CO_2 emissions. To enhance the energetic and environmental performance of the RD based processes, various process intensification techniques are explored. In this light, a novel thermally coupled RD (TCRD) and reflux splitting RD (RSRD) columns are formulated. Further improvements are achieved by devising vapor recompression and organic Rankine cycle arrangement for the conventional RD and RSRD column. This apart, two solar assisted RD based processes namely, CRD-PTC (conventional RD retrofitted with parabolic trough collector) and SRD (solar reactive distillation) are proposed towards substituting the fossil fuels driven heat utility by solar energy. Finally, an industrial scale process is proposed for simultaneous production of biodiesel and renewable hydrogen. This bi-fuel production process (BiFPP) integrates RD and glycerol steam reforming unit along with various separation units to get commercial grade biodiesel and hydrogen. The environmental impact and feasibility of the process are analyzed based on various key sustainability indicators like, green chemistry indices, economic indices and life cycle energy and CO_2 emission assessment. To achieve carbon neutrality, a CO_2 sink for algae cultivation is finally proposed to integrate with this industrial-scale BiFPP process that overall yields a novel zero discharge bi-fuel production technology.

Keywords: Algal biodiesel; reactive distillation; process intensification; multi-objective optimization; solar thermal energy; renewable hydrogen; CO_2 emission and cost